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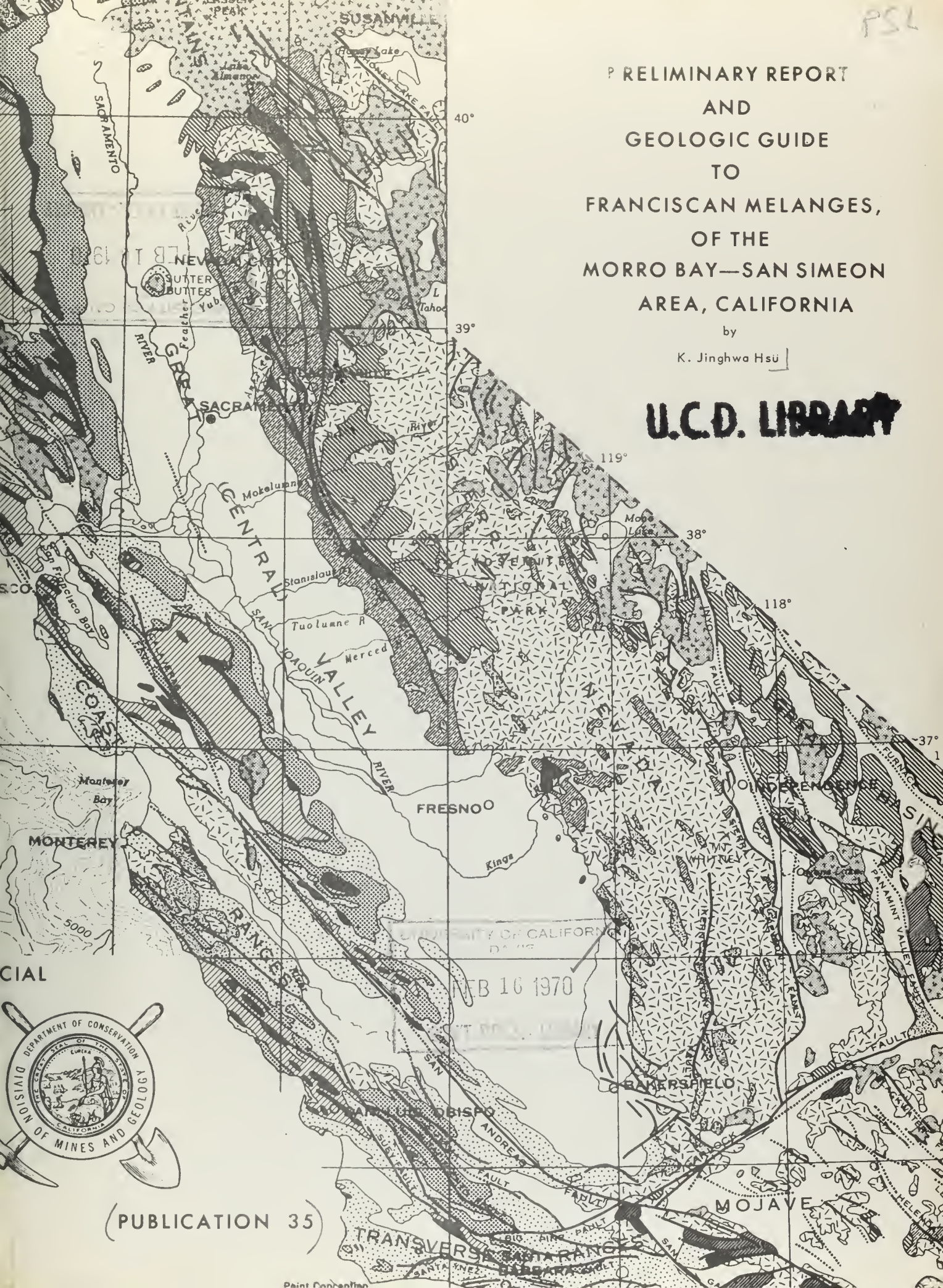

PRELIMINARY REPORT AND GEOLOGIC GUIDE TO FRANCISCAN MELANGES, OF THE MORRO BAY—SAN SIMEON AREA, CALIFORNIA

by

K. Jinghwa Hsü

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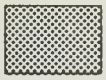
EXPLANATION

SEDIMENTARY AND VOLCANIC ROCKS

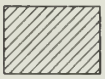
Cenozoic nonmarine (continental) sedimentary rocks and alluvial deposits

Cenozoic marine sedimentary rocks

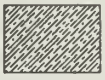
Cenozoic volcanic rocks



Late Mesozoic (latest Jurassic and Cretaceous) shelf and slope sedimentary rocks



Late Mesozoic (latest Jurassic and Cretaceous) eugeosynclinal rocks of the Franciscan Formation



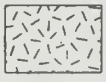
Mesozoic sedimentary and volcanic rocks older than the Nevadan orogeny; in places strongly metamorphosed

Paleozoic sedimentary and volcanic rocks; in places strongly metamorphosed; includes some rocks of Triassic age in Klamath Mountains; includes some late Precambrian sedimentary rocks in Great Basin

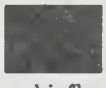
Precambrian rocks of all types including coarse-grained intrusives

Pre-Cenozoic metamorphic rocks of unknown age

INTRUSIVE IGNEOUS ROCKS



Granitic rocks chiefly of Mesozoic age



Ultramafic rocks chiefly of Mesozoic age

from

GEOLOGIC MAP OF CALIFORNIA

Scale 1:2,500,000

Compiled by U. S. Geological Survey in cooperation with

California Division of Mines and Geology, 1965

初告与美州加省山麥曼麻路海灣區法蘭丝市乾雜石磧指南

PRELIMINARY REPORT AND GEOLOGIC GUIDE TO FRANCISCAN MELANGES OF THE MORRO BAY–SAN SIMEON AREA CALIFORNIA

K. Jinghwa Hsü
Swiss Federal Institute of Technology
Zurich, Switzerland
1969

CALIFORNIA DIVISION OF MINES AND GEOLOGY

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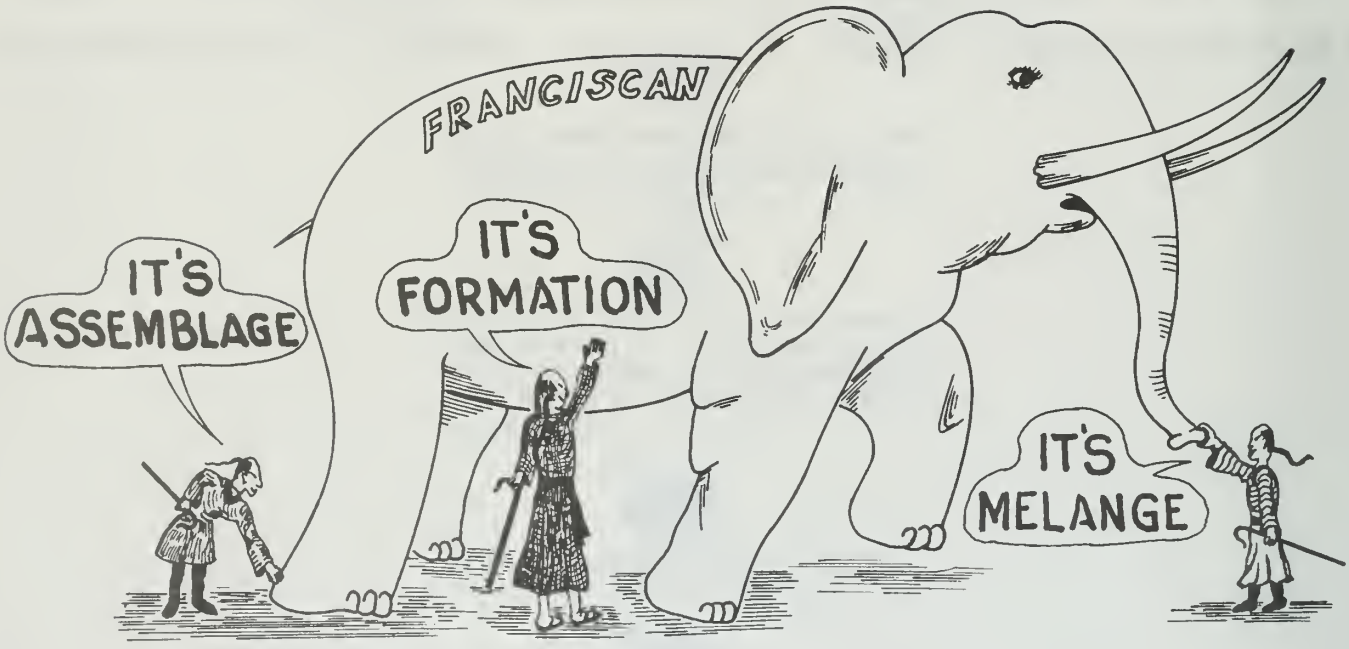

Based on a sketch in an announcement of a talk presented by Clark Blake before the National Center for Earthquake Research, Menlo Park, Calif., Oct. 30, 1969.

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FOREWORD

The Santa Lucia Range west of the Nacimiento fault is underlain largely by Late Mesozoic rocks, which are locally concealed under a Tertiary cover. These Mesozoic rocks are characterized by a general destruction of original junctions, whether igneous or sedimentary, especially of bedding, and by the shearing-down of the more ductile material until it functions as a matrix in which the fragments of the more brittle rocks float as isolated lenticles or phacoids.

This style of deformation is developed on a great scale. In a country of such tectonic fragmentation, the larger masses constitute mappable units. Some sedimentary units have been correlated faunally and lithologically to the Late Jurassic and Cretaceous formations on the west side of the Great Valley. Large igneous rock bodies can also be separated as distinct lithologic units. On the Geologic Map of California, scale 1:250,000, the mappable tectonic fragments appear as if embedded in a homogeneous and structureless matrix, the undifferentiated Franciscan. However, this country rock itself is built up of interdigitating lenticular bodies. Therefore, we could consider the region as a whole, some 1,500 square miles, a melange of torn and sheared lenticular masses of all sizes, from ten or twenty miles long, to the smallest the eyes can see, composed of spilitic lava, diabase, gabbro, serpentine, chert, graywacke, limestone, glaucophane schist and other metamorphic rocks.

This melange is variable spatially. The differing natures and origins of the blocks in different parts of the melange have been made the basis for establishing tectono-stratigraphic units, also known as the melange units. The preliminary map in this report shows the distribution of such units in the San Simeon - Morro Bay area.

The main purposes of the accompanying geologic guide are: (1) to refer the reader to outcrops which contain features illustrating the deformational style of this widely-distributed Franciscan melange, and (2) to inspire discussions on the possible relation of this particular deformational style to underthrusting of oceanic trenches and/or to gravity sliding.

It is hoped that the departures from normal methods of map portrayal and discussions of stratigraphic and tectonic units in this report will lead to a better understanding of the complex geologic problems of the region.

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PRELIMINARY REPORT AND GEOLOGIC GUIDE TO FRANCISCAN MELANGES OF THE MORRO BAY-SAN SIMEON AREA, CALIFORNIA

ABSTRACT

The Morro Bay-San Simeon area is underlain by both rock-stratigraphic units and chaotically deformed melange units. Structural interpretations suggest that allochthonous, meso-allochthonous, and neo-authochthonous rocks are all present.

The allochthonous Franciscan rocks, which include the Steinmann's Trinity and type I graywackes, were partially metamorphosed to glaucophane schist and deformed by overthrusting during the Late Jurassic.

The meso-allochthonous rocks include types II and III graywackes, and Knoxville-like rocks. They occur as slabs or smaller tectonic inclusions in melanges. These rocks range from Tithonian to Late Cretaceous in age, and are thus coeval in part with the Great Valley sequence. The meso-allochthonous rocks contain abundant older Franciscan debris and were deposited unconformably above an allochthonous basement. Both the meso-allochthonous cover and its basement were deformed by gravity sliding during the Late Cretaceous. The Franciscan melanges of the Morro Bay-San Simeon area were formed through tectonic fragmentation and mixing during this Late Cretaceous deformation.

The neo-autochthonous rocks include the uppermost Cretaceous (Campanian and Maestrichtian) Asuncion Formation and the Miocene Vaqueros and Monterey Formations. These formations, together with the underlying, originally subhorizontal melange units, were deformed during the Cenozoic into northwest-trending folds.

The Morro Bay-San Simeon area is at the southern end of the Santa Lucia Range (fig. 1). The geology of the area is similar to that of the other parts of the California Coast Ranges, whereby the Cenozoic and uppermost Mesozoic rocks are underlain largely by Franciscan rocks.

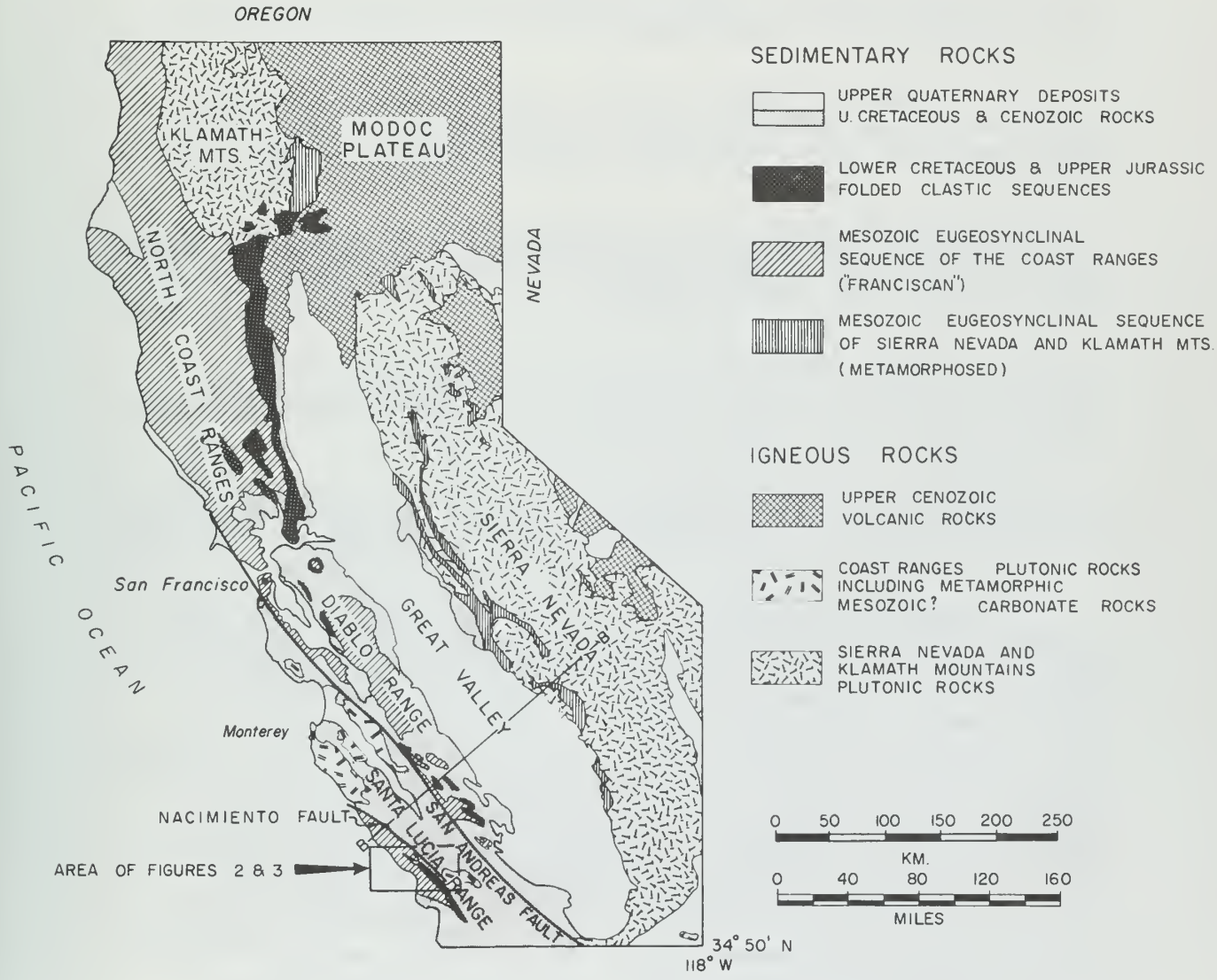


Figure 1 Index map and geologic sketch map of part of California.

Fairbanks (1904) mapped the area near Morro Bay. Taliaferro and his students carried out a regional mapping project north and east of San Simeon (Taliaferro, 1944). Their maps were largely unpublished, but have been compiled and incorporated in the San Luis Obispo sheet (scale 1:250,000) of the Geologic Map of California (Jennings, 1959).

Previous workers have largely assumed that the Franciscan rocks were autochthonous. However, my work in the past five years indicates:

(1) The Franciscan rocks are characterized by their deformational style, which is similar to that of the argille scagloise of the Apennines (Hsu, 1965a; 1967a)

(2) The melange concept should be applied to interpret the Franciscan geology and melange units should be used to supplement the conventional rock-stratigraphic units in mapping the Franciscan terranes (Hsu, 1966b; 1968)

(3) The Franciscan rocks are allochthonous or meso-allochthonous and were transported to their present sites by overthrusting and by gravity sliding (Hsu, 1965b; 1966a)

(4) The Franciscan rocks that yielded Cretaceous fossils locally are meso-allochthonous and were incorporated as tectonic inclusions in the Franciscan melanges during late Cretaceous gravity sliding (Hsu, 1968; Hsu and Ohrbom, 1969).

These ideas led to a new synthesis of well-known and newly uncovered facts on Franciscan geology and contributed to this present interpretation of the geology of the Morro Bay-San Simeon area.

The present report, based mainly upon field work in 1963 (May-September) and 1966 (June-September), and upon laboratory studies during 1964-1966, presents tentative conclusions, based upon preliminary data. Considerable amounts of field and laboratory data used in support of those conclusions are still to be processed and will be presented in a final report in the near future. The research was supported by the Shell Development Company, the National Science Foundation (Grant GP 4634), and by the University of California (several intramural grants). I gratefully acknowledge the financial assistance rendered by these institutions. Seymour Schlanger, Frank W. Dickson, Bennie W. Troxel, and Earl W. Hart read earlier drafts of the manuscript and their critical comments are appreciated. Dr. William R. Evitt examined some pollen and spore samples. His results, quoted in this paper, have been helpful to the structural interpretations presented herein.

This work is dedicated to the memory of my late wife Ruth, who assisted me in the field and helped in many ways during the earlier phases of the investigation.

NOMENCLATURE

Definitions of new and rarely used terms are necessary for precise description of the complex geologic history of the region.

Nomenclature of Map Units

Map units are mappable bodies of rocks. Three kinds of map units could be used to map the Franciscan rocks: rock-stratigraphic units (formations), tectonic units (melange units, slabs), and lithologic units.

Rock-Stratigraphic Units

Where the original stratal continuity is preserved, formation is the fundamental map unit. Where this continuity has been much disturbed by boudinage, wedging, or other intrastratal shearing, the formation is designated a "broken formation" (Hsu, 1968). Broken formations contain only native tectonic inclusions, which were once interbedded with the pelitic matrix, but no exotic blocks. A formation or a broken formation includes closely related strata, and therefore, can be characterized or dated by the assemblages of fossils found therein (Hsu, 1968).

Tectonic Units

Melanges resulted from fragmentation and mixing. Rocks detached from fragmented rock-stratigraphic units constitute tectonic inclusions in a melange. These inclusions can be classified on the basis of their maximum dimension. The classification used in this paper is as follows:

Large slabs	5000 feet or larger
Small slabs	500 to 5000 feet
Large blocks	50 to 500 feet
Small blocks	5 to 50 feet
Fragments and chips	5 feet or smaller

Slabs are mappable as tectonic units (fig. 2 and 3) or as lithologic units. Small tectonic inclusions, however, do not constitute mappable units on small-scale maps, and are, therefore, commonly mapped together with matrix as "undifferentiated melange". This practice results in the elimination of a vast amount of information, because laboriously collected data on the nature and distribution of unmappable blocks and fragments cannot be represented on such a geologic map. To remedy this difficulty, I proposed to subdivide melanges on the basis of the geographic variation of their composition, and to map melange units which are characterized by different assemblages of tectonic inclusions (Hsu, 1968).

Lithologic Units

Large tectonic inclusions of distinct lithology but of uncertain stratigraphy are mappable as lithologic units. For example, large slabs of ultramafic rocks and of greenstone have been shown on the 1:250,000-scale Geologic Map of California, whereas "undifferentiated Franciscan" designates areas underlain by melange matrix, and by tectonic inclusions unmappable on such a scale. On larger scale maps, such as 1:62,500 (e.g., Crittenden, 1951; Gealy, 1951; Travis, 1952), small slabs, or even some large blocks, of distinct lithology have been mapped. Lithologic units are not necessarily equivalent to rock-stratigraphic units: Mappable tectonic inclusions of identical lithology (e.g., pillow lavas) constitute one lithological unit but may have been derived from more than one formation.

Nomenclature of Tectonic Designations

Melange units include rocks that have been transported for long distances during one or more period of overthrusting or gravity-sliding. Several terms used by Italian geologists to designate the histories of tectonic transport in the Apennines will be used in this report, defined as follows:

(1) "Allochthonous" rocks are those that have been deformed by overthrusting or by gravity-sliding and have been transported for considerable distance from their original site of deposition.

(2) "Meso-allochthonous" rocks are those rocks that were deposited upon an allochthonous basement, and which were transported for considerable distance from their original site of deposition during a later episode of allochthonous deformation. A meso-allochtonous slab may include only meso-allochthonous sediments, or it may include both the meso-allochthonous sediments and some of their

basement that has been deformed by two or more episodes of allochthonous movements.

(3) "Autochthonous" rocks are those rocks that have not been transported from their original site of deposition.

(4) "Neo-autochthonous" rocks are those rocks that were deposited upon allochthonous rocks after all allochthonous deformations had taken place.

Explanation of Maps

The rocks of the Morro Bay-San Simeon region could be divided into three groups on the basis of their deformational history:

(1) Neo-autochthonous formations, with their original stratal continuity preserved because they were deposited after Late Cretaceous gravity sliding.

(2) Formations, largely meso-allochthonous, found within large slabs, with their original stratal continuity more or less preserved because the slabs moved en bloc.

(3) Melange units, representing different mixtures of allochthonous and meso-allochthonous inclusions in a tectonic matrix of pelitic composition.

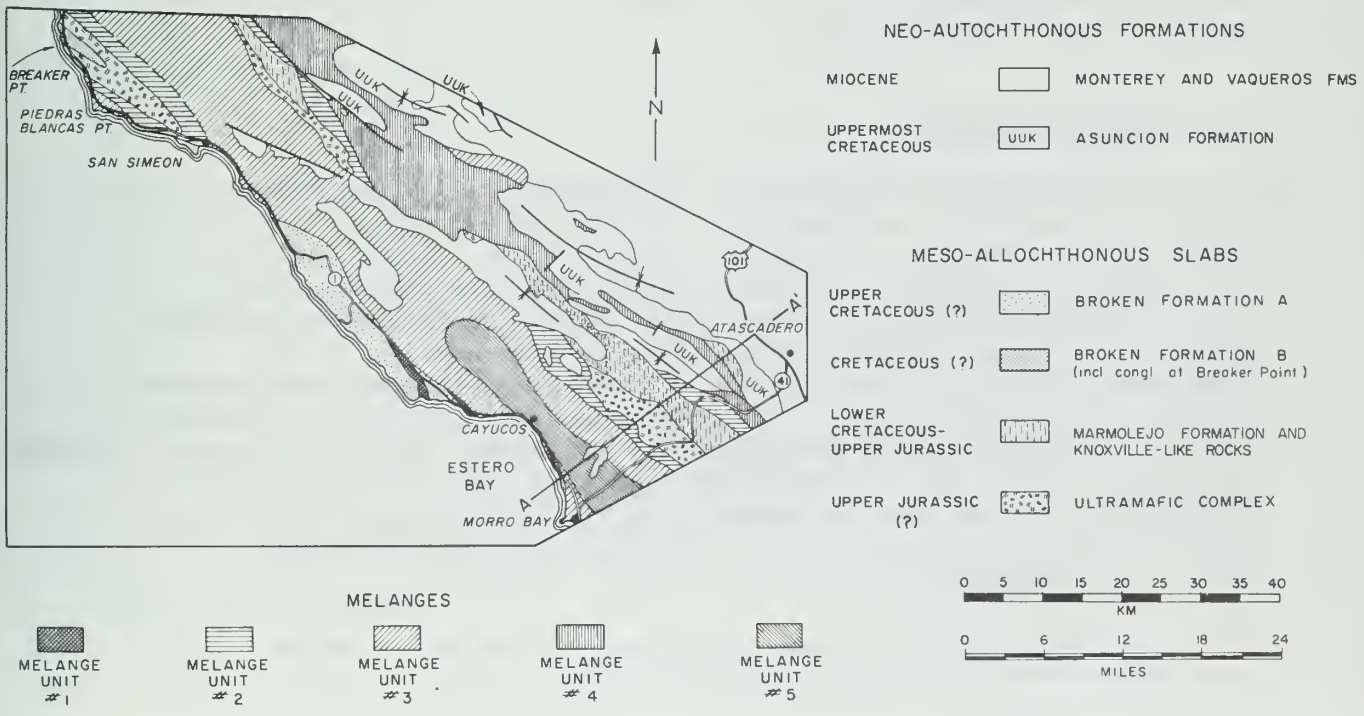


Figure 2 Sketch geologic map of the Morro Bay-San Simeon area.

Figure 2 is a sketch geologic map of the region showing the distribution of these 3 groups of rocks. The basic map is a composite map showing formations (rock-stratigraphic units) and melange units (tectonic units).

Figure 3 shows the distribution of small and large slabs of the region. The slabs are tectonic units, but those composed of one rock type only can be considered lithologic as well as tectonic units. A comparison of figures 2 and 3 shows that a meso-allochthonous formation may constitute all (e.g., "broken formation A") or a part (e.g., Marmolejo Formation) of a large slab.

STRATIGRAPHY

Franciscan Rocks

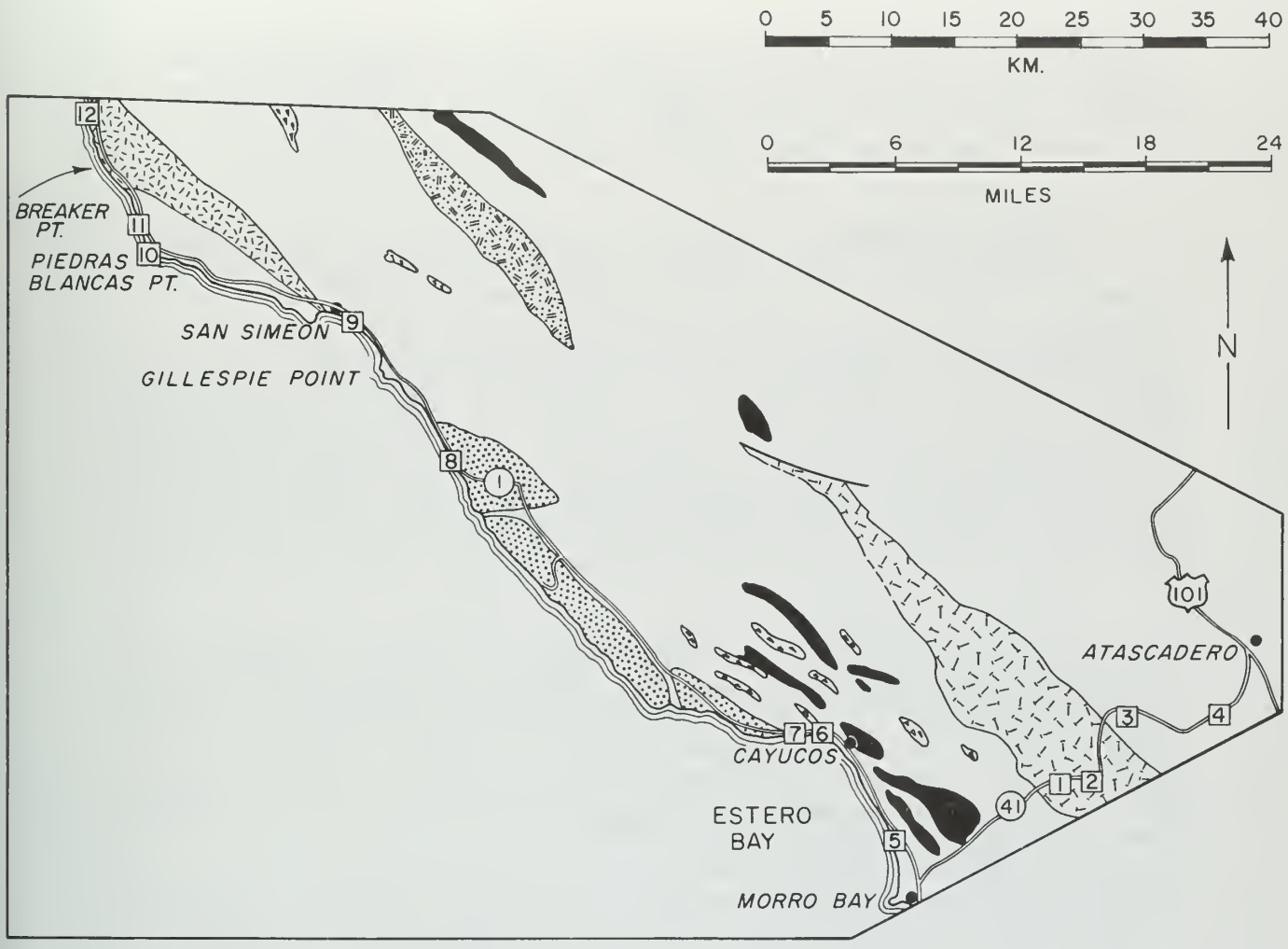
Franciscan rocks of the Morro Bay-San Simeon region are largely melanges. Their stratigraphy cannot be established on a presumption of normal superposition (Hsu, 1968). One must adopt the approach of interpreting the stratigraphy of the clasts in a breccia by attempting to recognize lithologically distinct clasts. He must then determine the ages of the clasts on the basis of fossils or other criteria, and relate the clasts sequentially on the basis of probable relative ages and origins.

Rock Types in Melanges

The occurrence, lithology and probable age of the Franciscan rock types that have been recognized are discussed below.

Type I Graywackes. The type I graywackes are characterized by the absence of detrital K-feldspars. They consist of plagioclase, chert and volcanic detritus embedded in a muddy matrix. Some specimens show partial recrystallization and sutured grain boundaries. Quartz veinlets are common. The interbedded pelitic layer is commonly a slate, characterized by incipient development of fracture cleavage. The type I graywackes are typically fractured, and original stratification of thicker beds is commonly obscured. Blocks of this rock type tend to be associated with blocks of chert, basic volcanic rocks, and serpentinite.

The type I graywackes are widespread in the Coast Ranges. They are particularly well exposed in the Stanley Mountain area east of



TECTONIC UNIT (LITHOLOGIC UNIT COMPONENTS)

BLACK MOUNTAIN SLAB (ULTRAMAFIC COMPLEX + MARMOLEJO FORMATION)

RED MOUNTAIN SLAB (ULTRAMAFIC COMPLEX + MARMOLEJO FORMATION)

HEARST RANCH SLAB (ULTRAMAFIC COMPLEX + CONGLOMERATE

CAMBRIA PINES SLABS (BROKEN FORMATION A)

SERPENTINE SLABS AND BLOCKS, BELONGING MAINLY TO THE MELANGE UNIT # 5

CHERT AND GREENSTONE BLOCKS

[3] FIELD TRIP LOCATION

Figure 3 Distribution of large and small slabs in Morro Bay-San Simeon area, showing also field trip locations.

Santa Maria. The graywackes associated with the serpentinite northeast of Morro Bay belong also largely to type I. Bailey and others (1964, p. 147) considered graywackes devoid of K-feldspars to be the oldest Franciscan clastic rocks, and probably pre-Knoxville.

Type II Graywackes. The type II graywackes are characterized by the presence of a small amount of detrital K-feldspar, which may range from traces to 10 percent, but more commonly from 2 to 5 percent. Locally these rocks include debris of chert and greenstone. Conglomerate and sedimentary breccia interbedded with type II graywackes also include such debris, as well as clasts of glaucophane schist, and type I graywackes. The presence of typically Franciscan rocks as debris in Franciscan graywackes and conglomerates has been recognized by many geologists since the turn of the century (Nutter and Barber, 1902; Fairbanks, 1904; Davis, 1918; Reed, 1933, p. 79; Taliaferro, 1943, p. 141), and has been cited as evidence that there are "breaks within the Franciscan itself" (Davis, 1918, p. 28).

The type II graywackes are generally less indurated than the type I graywackes. Type II graywacke beds are commonly fragmented by boudinage along extensional shear fractures or by wedging along shear planes subparallel to bedding. They are thus common as tectonic inclusions in Franciscan melanges. Where a tectonic inclusion of type II graywackes and interbedded strata attain the size of a slab, the sequence would be mappable on an-inch-to-the-mile map and could, therefore, be considered a broken formation. One such sequence is present north of the city of Morro Bay (Location 5, fig. 3). A similar sequence, but characterized by much more pronounced stratal fragmentation (photo 8) is present north of Piedras Blancas Point (Location 11, fig. 3). I shall refer to such sequences as "broken formation B",[1] for the sake of convenience.

W.R. Evitt of Stanford University examined 3 specimens of shale from "broken formation B" north of the city of Morro Bay and found all of them barren of identifiable remains of pollens and spores (letter dated 31 March, 1967). The K-feldspar content of type II graywackes is similar to that of Lower Cretaceous and Knoxville formations of the Great Valley sequence. Such an age assignment is consistent with the meager fossil evidence; for example, an Albian ammonite (Schlocker and others, 1954) is found in a type II graywacke of San Francisco Peninsula (Hsu and Ohrbom, 1969).

---

(1) "Broken formation B" is an informal rock-stratigraphic unit; detailed mapping has not been carried out.

Type III Graywackes. The type III graywackes are feldspathic (see Pettijohn, 1957, p. 291), consisting of plagioclase, K-feldspar, quartz, biotite, and interstitial clay. They show sedimentary structures typical of turbidity-current deposition: e.g., alternation of evenly-bedded graywacke and shale, bottom markings, shale inclusions in graywacke beds, graded bedding, cross-lamination, convolute lamination and others. However, the distinctive feature of the type III graywackes is their 10 to 20 percent K-feldspar content.

The sandstone and shale exposed along the coast west of the village of Cambria (e.g., Location 8, fig. 3) have been mapped by Taliaferro as a part of the Asuncion Formation (Jennings, 1959 and written communication). However, the sandstones are type III graywackes and are lithologically distinct from the typical arkose of the Asuncion (table 1). I believe, therefore, that the coastal rocks belong to a unit stratigraphically distinct from Asuncion.

Table 1

Distinction between Asuncion Formation and type III graywackes

	Asuncion Formation	Type III graywackes west of Cambria
Sandstone lithology	Arkose with abundant K-feldspars (about 30%)	Feldspathic graywacke with 10 - 20% K-feldspars
Conglomerate lithology	Abundant clasts of porphyry and granite	Few granite clasts; abundant Franciscan debris
Deformational style	Original stratal continuity retained	Original stratal continuity preserved locally; lozenge-shaped boudines common
Structural Interpretation	Neo-autochthonous	Meso-allochthonous slabs above a melange
Relation to other units	Unconformably overlies melange rocks	Contributes blocks to an underlying melange

The stratal continuity of the type III graywackes is locally preserved (photo 1). However, lozenge-shaped boudines are also common (photo 2). The partly broken interbeds of type III graywackes and shale west of Cambria constitute a broken formation, designated here as "broken formation A". Type III graywackes have also been found as blocks in a melange unit immediately below a slab of "broken formation A".

The type III graywackes have a feldspar content comparable to the Upper Cretaceous rocks of California (see Bailey and others, 1964, p. 138). W.R. Evitt examined pollen and spores from two interbedded shale specimens(2) and wrote (letter dated March 31, 1967):

> "(The type III graywackes are) Upper Cretaceous, definitely, on the basis of Proteacidites thalmanni and the dinoflagellate Palaeohystrichophora infusorioides. The latter has a long range in the UK but is rare after the Campanian; therefore, I would guess Campanian or older. This agrees with the inferences from some spores that also have long ranges but are more common in California in earlier than in later Upper Cretaceous sediments."

The paleontological evidence is consistent with my interpretation that the type III graywackes are Upper Cretaceous (Hsu and Ohrbom, 1969).

Knoxville-like Rocks. Mappable bodies of Buchia-bearing siltstone and shale are characterized by a preservation of stratal continuity (photo 2). These evenly bedded rocks, similar lithologically and paleontologically to the Knoxville and lower Paskenta strata of the Great Valley sequence, have been mapped by Taliaferro (1944) as the Lower Cretaceous Marmolejo Formation, although the Buchia specimens from the formation include both Upper Jurassic and Lower Cretaceous species (see Bailey and others, 1964, pl. 1). They are present within large slabs and are found above the diabase and fine-grained gabbro of the same slabs (fig. 4). The contact between the sedimentary and igneous rocks is everywhere modified by minor faults. However, a conglomerate bed, characterized by pebbles of green chert and diabase, in addition to those of black chert and argillite, is present locally at the contact as a basal conglomerate.

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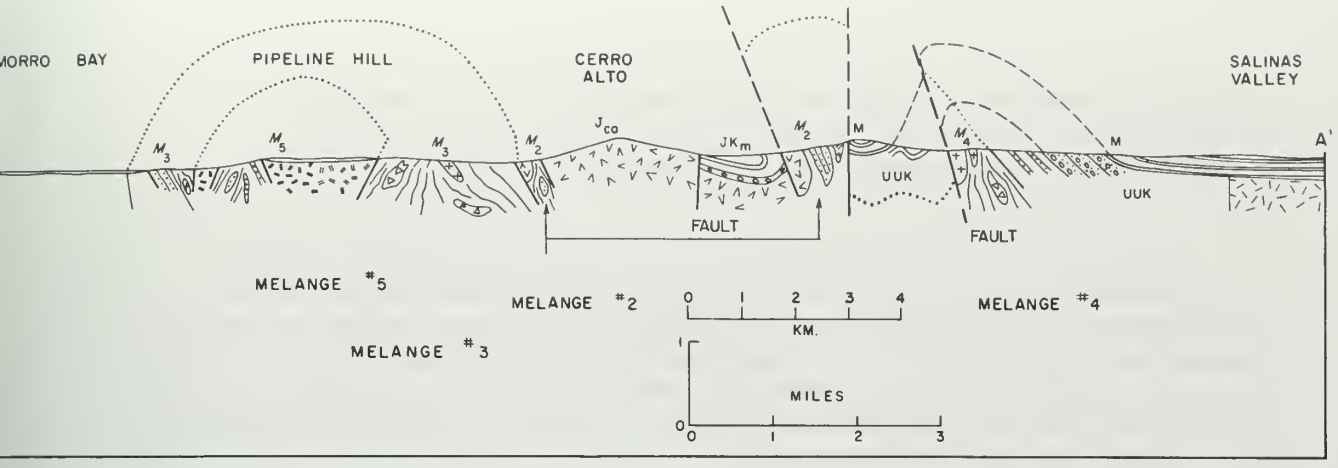
(2) Sample locations are:
TH-2. Dull gray shale interbedded with type III graywackes, at roadcut on State Highway 1, at NE corner Sec. 21, R. 9 E., T. 28 S.

TH-6. Dull gray shale interbedded with type III graywackes, on the coast at mouth of Leffingwell Creek, SW corner, Sec. 16, R. 8 E., T. 28 S.



M_2 - MELANGE UNIT #2
M_3 - MELANGE UNIT #3
M_4 - MELANGE UNIT #4
M_5 - MELANGE UNIT #5

M - MONTEREY AND VAQUEROS FORMATION
UUK - ASUNCION FORMATION
JK_m - MARMOLEJO FORMATION AND KNOXVILLE-LIKE ROCKS
J_{co} - ULTRAMAFIC COMPLEX
RECONSTRUCTED FRANCISCAN ANTIFORMS AND SYNFORMS
ANTICLINE AND SYNCLINE

Figure 4 Schematic structural cross-section along line A-A' of fig. 1 from Morro Bay to Atascadero.

Where the Knoxville-like rocks occur as tectonic inclusions too small to map, they have been lumped together with other tectonic inclusions and melange matrix and shown as undifferentiated Franciscan on a map (e.g., Jennings, 1959). This leads to the paradox of the Knoxville Formation unconformably overlying a Franciscan unit that contains coeval fossils (Hsu, 1968, p. 1070).

Red serpentinite breccia and the Franciscan serpentinite are present on the coast north of Breaker Point (Location 12, fig. 3). Serpentinite blocks, mainly red, ranging up to several feet long, were deposited upon a predominantly green serpentinite basement. Only the uppermost fossilized weathered surface of the basement has the redness of the breccia fragments. A few type II graywacke beds are intercalated in the breccia sequence. These graywacke beds include red serpentinite debris and 2 to 5 percent K-feldspar. This red breccia sequence was shown as a Miocene pyroclastic formation on the San Luis Obispo sheet (Jennings, 1959) of the Geologic Map of California. However, these rocks are definitely not pyroclastic. I have designated them Knoxville-like rocks because they are associated with siltstone and shale that have been mapped as Marmolejo (Jennings,

1959), and because, except for their red color, they resemble serpentinite breccia that is repeatedly found in the Knoxville-Paskenta part of the Great Valley sequence (Taliaferro, 1943, p. 206).

The lower part of the Knoxville-like sequence north of Morro Bay yielded Buchia piochii and B. crassicollis (Bailey and others, 1964, pl. 2). They should thus be Tithonian to Valanginian in age (Jones and others, 1966) and stratigraphically equivalent to Knoxville and Paskenta beds of the Great Valley sequence (see Popenoe and others, 1960; Bailey and others, 1964). The interbedded graywackes have a K-feldspar content similar to that of type II graywackes, ranging from traces and 2 percent, in the lower fossiliferous part of the sequence, up to 10 percent, in the higher unfossiliferous part.

Limestone. Limestone is present but very rarely in the Morro Bay-San Simeon region. A few small blocks and fragments have been found, for example, on the coast one mile due west of the northern city limit of Cayucos, where small blocks of limestone, together with type II graywackes and associated conglomerate, red chert, and blue schist, occur as tectonic inclusions in a melange. The limestone is recrystallized and no identifiable fossils have been found.

Lustrous Shale (Melange Matrix). The pelitic matrix of the melanges is highly sheared and has a highly lustrous appearance on sheared surfaces. Ten samples were analysed by X-ray diffraction method. The lustrous shale is found to consist predominantly of chlorite, with subsidiary amounts of mica.

Dull Gray Shale. The shales interbedded with broken formations of types II and III graywackes are dull gray and no lustrous on bedding plane surfaces. X-ray analyses of 10 samples showed that the shales consist of various proportions of chlorite, illite and mixed-layered clays, in contrast to the chloritic melange matrix. I have not yet carried out a thorough clay-mineralogy study to further subdivide the shales.

The dull gray shales associated with type II graywackes yielded no fossils. The two samples which yielded Upper Cretaceous pollen and spores are associated with type III graywackes.

Steinmann's Trinity. The association radiolarian chert-greenstone-serpentinite is a characteristic eugeosynclinal assemblage in Alpine-type mountain chains (Steinmann, 1927) and has been called the Steinmann Trinity by the late Sir E.B. Bailey (Bailey and McCallien, 1960). Radiolarian chert, greenstone, and serpentinite

are present in the Franciscan melanges of the San Simeon-Morro Bay area.

The Franciscan radiolarian cherts are commonly red or green, though bleached to yellow or white locally. They are closely associated with greenstone.

A chert-greenstone sequence occurs as a small slab at Piedras Blancas (Location 10, fig. 3). The top of the sequence is massive recrystallized chert, overlying thin bedded chert and interbedded chert and cherty shale. The chert sequence grades downward to basalt tuff and tuff breccia. The base of the slab is pillow lava, with well-defined pillows serving as geopetal criteria. A similar slab is exposed on the coast west of Cayucos (Location 6, fig. 3), where chert and greenstone are interbedded.

The third member of the Steinmann Trinity is a mafic-ultramafic complex. This complex is particularly well-exposed on roadcuts of State Highway 41 (Location 1, fig. 3). The base of the complex is a mass of highly weathered serpentinite, cut by numerous rodingite dikes (photo 3). This weathered ultramafic basement is apparently overlain by pillow breccia, with abundant fragments of broken pillows and a few scattered pillows. Higher up is a thick mass of very fine-grained gabbro and coarse diabase. This whole igneous complex is overlain by the Knoxville-like rocks (Location 2, fig. 3). The association of ultramafic complex with Knoxville-like rocks occurs in three large slabs in the report area (fig. 3). Small slabs and blocks of the melanges, have also been observed (e.g., at Gillespie Point).

Steinmann has designated (1927) the association of mainly extrusive basic igneous rocks with ultramafic intrusive rocks as the ophiolite suite. The suite commonly underlies the radiolarian chert, and the succession (in descending order) of basalt tuff, tuff breccia, pillow lava, fine-grained gabbro and ultramafic rocks has been repeatedly observed in the Tethyan mountain system (Moores et al., 1966; J. Maxwell, personal communication). Tectonic inclusions of igneous rocks from the Franciscan melanges of the report area are apparently derived largely from such an ophiolite suite.

Serpentinite. Slabs and blocks of serpentinite not associated with other members of the ophiolite suite are present in the area north of Morro Bay (fig. 3). Those masses may represent the basement of the ophiolite sequence. Alternatively, they might represent another ultramafic complex which was intrusive into older Franciscan rocks during the Late Jurassic. Gravity studies and detailed field mapping indicated that these serpentinite masses are tabular bodies

(Grannell and Hsu, 1967): such bodies probably represent slab-sized tectonic inclusions in melanges (Hsu and Ohrbom, 1969).

Metamorphic Rocks. Metamorphic rocks are not uncommon in the Franciscan melanges. Large and small blocks of glaucophane schist are well-exposed on the coast immediately north of Cayucos. The schists are metamorphosed equivalents of the Steinmann's Trinity, including glaucophane-bearing quartzite (meta-chert) and glaucophane-albite schist (meta-greenstone). These rocks, formed under high-pressure regional metamorphism (Ernst, 1965; Bailey and others, 1964), are now found in close association with unmetamorphosed chert and greenstone. The fact that Franciscan glaucophane schist commonly "occurs in relatively small areas in the midst of unaltered sediments" has been noted by Taliaferro (1943, p. 161), and by many before him, and has led them to postulate an origin by contact metamorphism (Taliaferro, 1943, p. 159-182). However, such occurrences are easily explained when we recognize that the schists are exotic blocks in melanges (Hsu and Ohrbom, 1969).

Masses of meta-greenstone characterized by a green schist facies assemblage of albite-actionolite-chlorite-epidote are also present locally as tectonic inclusions, but they are very rare (e.g., in gravel pit one mile northwest of Cayucos Point).

Schists from the Morro Bay-San Simeon region have not been dated. Isotope ages of glaucophane schist from elsewhere in the Coast Ranges are from 130 to 150 million years (Lee and others, 1963; Curtis quoted in Bailey and others, 1964, p. 105). These ages suggest a Late Jurassic metamorphism. If this interpretation is accepted, the presence of a pre-Tithonian Franciscan eugeosynclinal sequence can hardly be denied.

Ghent (1964) and Suppe (1969) identified, in addition to the Late Jurassic glaucophane-schist metamorphism, a Cretaceous phase of lawsonite-schist metamorphism in the northern Coast Ranges. Whether the Franciscan rocks of the Morro Bay-San Simeon area have been subjected to this second metamorphism cannot be determined by the local evidence.

Stratigraphical Reconstruction

A reconstruction of melange stratigraphy depends upon the formulation of a working hypothesis that is consistent with all known geological data. Three different hypothesis have been invoked to reconstruct the Franciscan stratigraphy:

(1) The Franciscan and Knoxville form a normal depositional cycle in Tithonian or latest Jurassic time (Taliaferro, 1943).

(2) The Franciscan rocks represent the eugeosynclinal equivalent of a miogeosynclinal Great Valley sequence (which includes Knoxville); the Franciscan rocks are, therefore, Tithonian and younger (Irwin, 1957; Bailey and others, 1964).

(3) Franciscan melanges include blocks detached from two units: a pre-Tithonian San Francisco unit, which originally underlay the Great Valley sequence unconformably, and a Tithonian and younger San Mateo unit, which is the western extension of the Great Valley sequence (Hsu and Ohrbom, 1969).

The first hypothesis was based on arguments now in conflict with the second rule of melanges (Hsu, 1968, p. 1067). The second rule states that "the stratigraphy of a melange sequence cannot be established based on a presumption of normal superposition". Taliaferro postulated a gradational contact between the Franciscan and Knoxville based upon his observations of the supposed interbedding of typical Franciscan rocks with fossiliferous Knoxville rocks of one of the critical localities in the Stanley Mountain area in the Nipomo quadrangle, San Luis Obispo County, he wrote (1943, p. 198):

> "in this region...north of the Cuyama River, there is a clear and unmistakable example of beds with typical Franciscan lithologic character but which contain fossils supposed to be characteristic of Knoxville."

This clear and unmistakable example was questioned by Bailey and others (1964, p. 122), by Hall and Corbato (1967, p. 564), and by Brown (1967). I have visited this locality several times and found that the apparently homoclinal sequence of "interbedded" Franciscan greenstone, chert, and Knoxville shale (shown by the structural profile of Taliaferro, 1943, fig. 7) is in fact a body of melange composed of slabs and blocks of various lithologies and different origins. Jurassic fossils are present in limestone (Easton and Imlay, 1955), which, I found, is interbedded with Knoxville sandstone but separated from Franciscan rocks by shear surfaces. Taliaferro's statement is in conflict with the second melange rule, in that he assumed normal stratigraphic succession of Franciscan and fossiliferous Knoxville beds that are separated by tectonic contacts. It is not surprising, therefore, that Taliaferro's hypothesis of pre-Cretaceous Franciscan is proven wrong by the discoveries of numerous Cretaceous fossils in Franciscan rocks (Irwin, 1957; Bailey and others, 1964).

The second hypothesis above was proposed on the basis of arguments now in conflict with the third rule of melanges (Hsu, 1968,

p. 1067). The third rule states that "the assignment of a time-range of deposition to all the rocks in a melange on the basis of the oldest and youngest fossils found in such a melange is wrong". I have gone into considerable length to prove that the Franciscan rocks include pre-Tithonian rocks (Hsu, 1968; Hsu and Ohrbom, 1969) and shall not repeat all the arguments again. Suffice to say, the existence of Franciscan rocks, which had been metamorphosed already during Late Jurassic (Lee and others, 1964; Bailey and others, 1964, p. 105; Suppe, 1969), is a fact that contradicts the hypothesis that all Franciscan rocks are Tithonian and younger equivalents of the Great Valley sequence.

We are, therefore, left with the third alternative as a working hypothesis. All rock types are present as tectonic inclusions now, but they must have been derived from some stratigraphical units which have been disintegrated during melange deformation.

What are those units? They have been disintegrated and are, therefore, no longer mappable rock-stratigraphic units. They are stratigraphic units which can be recognized only from the clasts in tectonic breccia. I have suggested the expression "phantom-stratigraphic units" and proposed that it be applied to two units of the type Franciscan at San Francisco Peninsula (Hsu and Ohrbom, 1969): A pre-Tithonian unit (San Francisco unit) which furnished type I graywackes and rocks of the Steinmann's Trinity as clasts to the Franciscan melanges, and a Tithonian-Upper Cretaceous (San Mateo unit) unit which furnished types II and III graywackes and Knoxville-like rocks to the melanges. The latter, but not the former, is coeval, or partly coeval, to the Great Valley sequence.

This stratigraphical interpretation of type Franciscan provides a basis for the stratigraphical reconstruction shown by table 2. The meager fossil evidence is consistent with this reconstruction.

Neo-Autochthonous Formations

The neo-autochthonous rocks of the area include the Miocene Monterey and Vaqueros Formations and uppermost Cretaceous Asuncion Formation. These rock-stratigraphic units have been defined and mapped by Fairbanks (1904) and by Taliaferro (1944), and unpublished in Jennings (1959).

The strata of neo-autochthonous formations have not been disrupted by pervasive shears, nor do they occur as tectonic inclusions in Franciscan melanges. The conglomerate and sandstone beds of these formations are arkosic. These rocks unconformably overlie the

Franciscan rocks on the southwest of the Nacimiento fault, and the Coast Ranges batholith on the northeast side of the fault.

Table 2

Stratigraphical Reconstruction of the Franciscan rocks of

Morro Bay-San Simeon Region

Age	Phantom Units	Tectonic inclusions derived from such phantom-stratigraphic units
Upper Cretaceous (Campanian and older)	San Mateo unit	Broken formation A, type III graywackes.
Lower Cretaceous to uppermost Jurassic		"broken formation B", Marmolejo Formation, type II graywackes, and Knoxville-like rocks
		Major Unconformity
Upper Jurassic and older (Pre-Tithonian)	San Francisco unit	Type I graywackes, Steinmann's Trinity (radiolarian, chert; upper ophiolites, viz., greenstone and pillow basalt; lower ophiolites, viz., ultramafic rocks); and their metamorphosed equivalents.

The oldest fossils from any neo-autochthonous unit in the Morro Bay-San Simeon area were found in the upper part of the Asuncion Formation, and indicate Campanian to Maestrichtian ages (Taliaferro, 1944; Popenoe, et al., 1960). This date suggests that the allochthonous deformation of the Franciscan rocks took place during Campanian and earlier times. The possibility of minor sliding movements of neo-autochthonous rocks cannot be ruled out, as chaotic

and/or decollement structures have been observed locally in Tertiary rocks of the Coast Ranges, related to episodes of Cenozoic deformation (e.g., Dickinson, 1966; Page and Tabor, 1967).

GEOLOGIC STRUCTURES

Deformational Styles and Their Implications

The distinctive deformational style of the Franciscan rocks is the fragmentation of original stratal continuity. This style results from the different mechanical behaviors of rocks. The graywacke is characterized by brittle deformation, particularly shear failures along compressional and extensional shear joints. The pelitic rocks are characterized by ductile flowage, serving as matrix for the broken fragments. This style of deformation is well shown by photos 2 and 8.

The ophiolites have a more complicated deformational history. The flowage structures of glaucophane schist and the minor chevron folds of radiolarian chert bear witness to an episode of ductile deformation. However, they are now present as angular blocks in a pelitic matrix, indicating a brittle behavior during a later episode of deformation.

The serpentinite and ultramafic rocks have an even more complicated deformational history: They are present as angular slabs and blocks in Franciscan melanges. However, serpentinite schist is present in the cores of faulted anticlines, apparently intruding as diapirs into younger rocks during Cenozoic deformation (Taliaferro, 1943, p. 206; Eckel and Myers, 1946; Bailey and others, 1964, p. 155). However, in the melange terranes of the report area, serpentinite and associated gabbro and peridotite occur mainly as angular tectonic inclusions in a ductily deformed pelitic matrix, which locally includes materials derived from the serpentinite.

The chaotic Franciscan structures we see today result from a mixing of rigid blocks in a ductile matrix. Such melange structure is particularly displayed on the coast near Cayucos (Locations 6 and 7, fig. 3) and near San Simeon (Location 9, fig. 3), and is illustrated by photos 5, 6, 7.

The pervasive shearing and chaotic mixing style of deformation is to be expected of gravity-sliding tectonics from a theoretical

standpoint (Hsu and Ohrbom, 1969). This style is indeed present in the Apennines, where gravity sliding tectonics predominates (Bailey and McCallien, 1963; Page, 1963; Maxwell, 1963; Hsu, 1967b). I have, therefore, interpreted the melange structures of Franciscan rocks as the result of gravity-sliding deformation (Hsu, 1967a) and have compared its movement to slow landslipping movements, which are observable on a small scale today (Hsu and Ohrbom, 1969). The age of this deformation is dated as Late Cretaceous because Upper Cretaceous type III graywackes are involved, but the uppermost Cretaceous Asuncion Formation is not.

The style of the Late Jurassic deformation of presumed pre-Tithonian Franciscan rocks can be gleaned from the minor structures within the rocks. The mineralogy and the flowage structures of the glaucophane schist are suggestive of Alpine deformation. I have, therefore, postulated an epoch of overthrusting and metamorphism prior to Cretaceous gravity-sliding (Hsu, 1966b; 1967a, p. 293).

Mapping of Melanges

In mapping melanges, tectonic units must be recognized to supplement rock-stratigraphic units. Figures 2 and 3 show, in addition to formations, two types of tectonic units -- slabs and melange units.

Franciscan Slabs

Slabs, as we have defined them, are tectonic inclusions within a melange terrane that are larger than 500 feet. Since slabs moved en bloc during the melange deformation, the stratal continuity of formations within the slabs is essentially preserved (Hsu, 1967b). Individual formations within the slabs are thus mappable rock-stratigraphic units and are shown as such in fig. 2. The distribution of slabs are shown by fig. 3.

Three large slabs consist of a mafic-ultramafic complex (lower ophiolite) and its meso-allochthonous cover composed of Knoxville-like strata. The Black Mountain and the Red Mountain slabs underlie a northwest-trending syncline of neo-autochthonous formations near the crest of the Santa Lucia Range drainage divide. The stratigraphy of the two slabs is very similar; they might have been originally continuous but are now isolated, possibly as a result of erosion. The more westerly third slab (Hearst Ranch slab) includes the serpentine breccia at Breaker Point and its underlying basement. This slab has also been deformed into a northwest-trending synform during the Cenozoic.

Melange Units

The large slabs can be shown on a small scale map (fig. 3) but the small slabs, blocks and fragments of various rock types individually do not constitute mappable units. I have, therefore, resorted to the technique of mapping melange units, as discussed in my previous articles (Hsu, 1968; Hsu and Ohrbom, 1969). This practice is based upon the observation that a large melange body is variable geographically. The differing natures and origins of the blocks and matrix can, therefore, be made the criteria for subdivision.

Five melange units have been recognized in the Morro Bay-San Simeon area. Melange unit 4 is present east of the Black Mountain-Red Mountain slabs, and its correlation with other melange units is uncertain. Unit 4 is, therefore, distinguished by its geographical isolation as well as by a somewhat different assemblage of tectonic inclusions. The other four units are, however, recognized mainly on the basis of distinct associations of tectonic inclusions.

As shown by table 3, melange unit 1 is characterized by the presence of type III graywackes, which obviously have been detached from the "broken formation A" of the overlying slab (fig. 2). Unit 2 is characterized by the presence of many tectonic inclusions detached from the overlying Black Mountain and Red Mountain Slabs, such as Knoxville-like rocks, the gabbro and the ultramafic rocks from the basement complex. Unit 3 is characterized by the presence of practically all Franciscan rock types except type III graywackes; chert, greenstone, and type II graywackes are most common. Unit 5 is characterized by the predominant inclusions of serpentinite.

The distribution of the various melange units is shown by figure 2. These melange units may represent sheets or wedges of originally sub-horizontal gravity-slide masses underlying large slabs. Units 1 and 2 apparently occupy the highest tectonic position directly under large slabs. Units 3 and 4, in intermediate position constitute the main body of melanges. Unit 5 may represent the lowest melange unit.

A like succession of similar melange is present in the so-called type area of the Franciscan rocks, the San Francisco Peninsula (Hsu and Ohrbom, 1969). As in the "type area", the melange units of the San Simeon-Morro Bay region have been folded into plunging antiforms and synforms, parallel to the anticlines and synclines of neo-autochthonous rocks (fig. 2 and 4). The early folding was pre-Miocene, as nearly flat-lying strata of the Miocene Vaqueros Formation unconformably overlie the steeply-dipping melange unit 5 north of Morro Bay. A later Plio-Pleistocene deformation, which folded the Miocene Vaqueros and Monterey Formations into northwest-trending anticlines, may have steepened the dips of melange shear planes in some areas.

Table 3

Composition of melange units

Rock types	Tectonic Inclusions in Melange Units				
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Type I graywackes		xx	x	xx	x
Type II graywackes	xx	x	xx	x	/
Type III graywackes	xx				
Knoxville-like rocks		xx	/		
Chert and greenstone	xx	x	xx	xx	x
Diabase, gabbro and associated ultramafic rocks		xx	x		
Serpentinite	xx		x	x	xxx
Metamorphic rocks			x		
Limestone			x		

/ rare
x present
xx common
xxx predominant

GEOLOGIC HISTORY

If the pre-Tithonian Franciscan rocks are largely allochthonous, their original site of deposition must have been outside of the Coast Ranges. In the region where the Sierra Nevada foothills now stand was also a Jurassic eugeosyncline, in which pyroclastic rocks and pelitic sediments, as well as rocks of the Steinmann's Trinity, were deposited (Clark, 1964). These rocks could be genetically related to the pre-Tithonian Franciscan rocks: The dominantly pyroclastic igneous suite of the Sierra Nevada foothills may represent the shoreward equivalent of the Franciscan ophiolites, and the dominantly pelitic Mariposa Slate may represent a slope facies equivalent of the Franciscan trough turbidites. I have, therefore, suggested that the pre-Tithonian San Francisco unit was deposited in a trough somewhere in eastern Great Valley (Hsu, 1967; Hsu and Ohrbom, 1969).

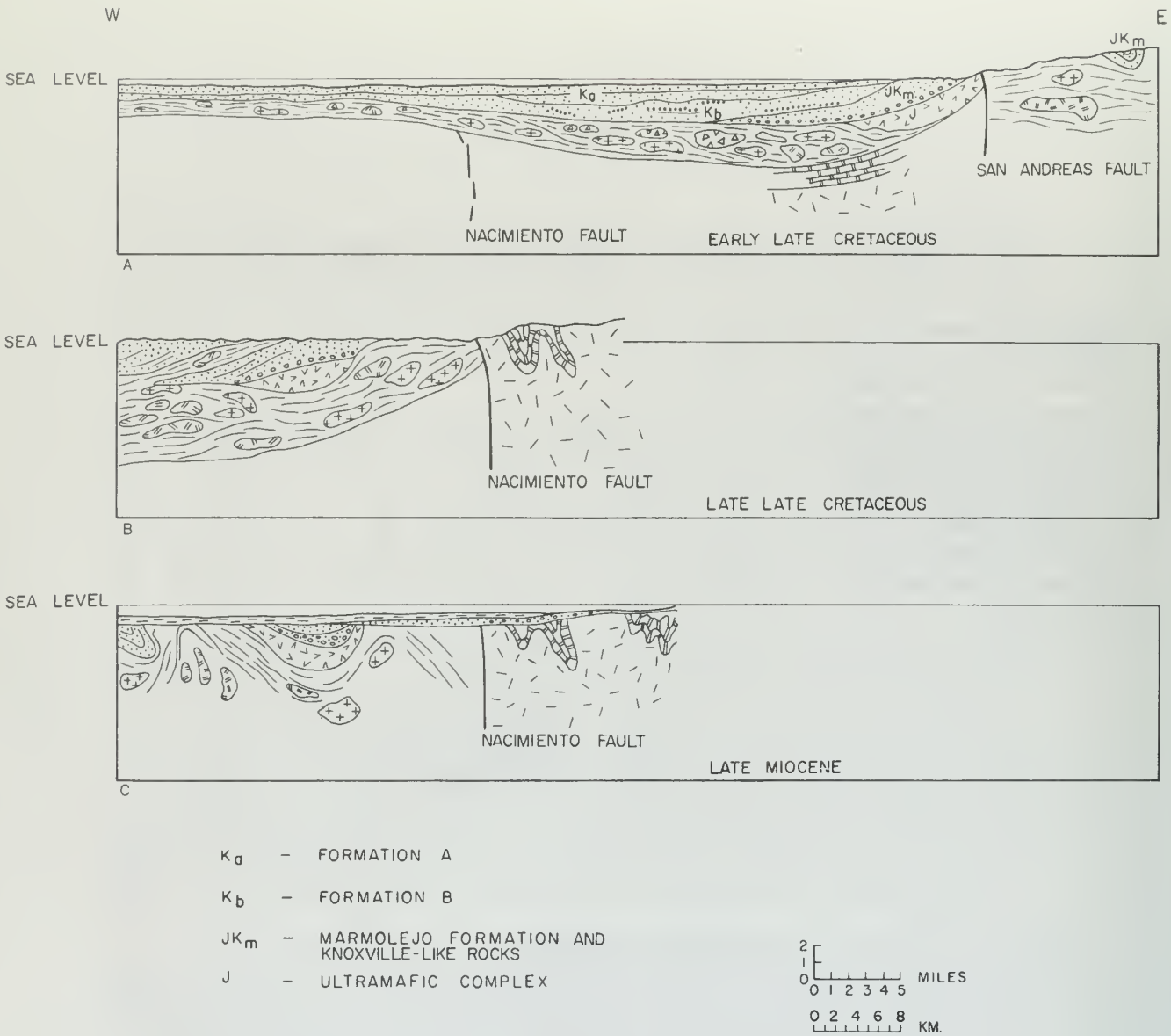


Figure 6 Late Mesozoic geologic history of the Santa Lucia Range.

a) Deposition of the meso-allochthonous San Mateo unit of Late Jurassic to Late Cretaceous age on an allochthonous basement of San Francisco unit during the Tithonian to Late Cretaceous interval.

b) Gravity sliding of the meso-allochthonous rocks and their underlying allochthonous basement during Late Cretaceous.

c) Deposition of neo-autochthonous Miocene rocks.

The meso-allochthonous San Mateo unit represents the western extension of the Great Valley sequence. It could only have been deposited upon the pre-Tithonian Franciscan rocks after the latter were brought into the Coast Ranges by westward thrusting.

I have presented arguments to show that the San Mateo unit was detached from the Great Valley sequence and arrived at its present position as blocks and slabs in melanges after Late Cretaceous gravity-sliding movements (Hsu and Ohrbom, 1969). The interpretation by Bailey, Irwin and Jones (1964) that the Great Valley sequence of Sacramento Valley was thrust above the Franciscan melanges is questionable, because their interpretation can now be demonstrated to be in conflict with Hsu's fifth melange rule, which states that "the rock stratigraphic unit overlying a melange can be autochthonous in one place and allochthonous elsewhere" (Hsu, 1968, p. 1070).

On the evidence of an allochthonous and polygenetic Franciscan, I shall summarize my interpretation of the geologic history of the Coast Ranges as follows:

(1) Deposition and emplacement of an ophiolite sequence during Mesozoic time, in the area west of the Sierra Nevada foothills, probably upon an ultramafic basement.

(2) Deposition of the type I graywackes during Late Jurassic above the ophiolite (fig. 5a).

(3) Late Jurassic deformation and partial metamorphism of the eugeosynclinal sequence, emplacement of ultramafic intrusive masses, and westward overthrusting of the partly metamorphosed eugeosynclinal rocks (fig. 5b).

(4) Deposition of the latest Jurassic to Late Cretaceous meso-allochthonous Franciscan sediments (e.g., Knoxville-like rocks, "Marmolejo Formation") on allochthonous pre-Tithonian Franciscan rocks (figs. 5c, 6a).

(5) Rise of the Coast Ranges batholith, deformation and metamorphism of the carbonate sediments and their basement to constitute the Sur Series, and westward gravity-sliding of the allochthonous Franciscan rocks and their meso-allochthonous cover (fig. 6b).

(6) Deposition of neo-allochthonous rocks and their subsequent deformation (figs. 5d, 5e, 6c).

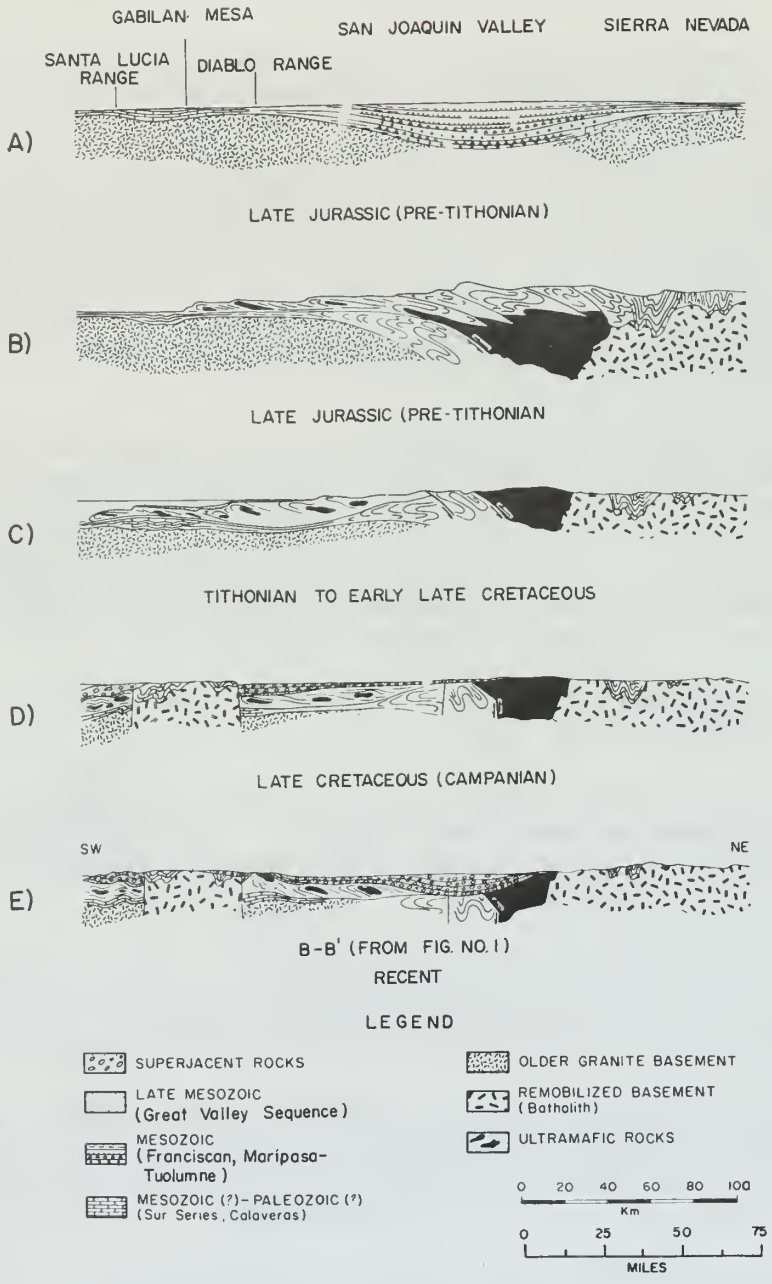

GABILAN MESA
SAN JOAQUIN VALLEY
SIERRA NEVADA
SANTA LUCIA RANGE
DIABLO RANGE
A)
LATE JURASSIC (PRE-TITHONIAN)
B)
LATE JURASSIC (PRE-TITHONIAN
C)
TITHONIAN TO EARLY LATE CRETACEOUS
D)
LATE CRETACEOUS (CAMPANIAN)
SW
NE
E)
B-B' (FROM FIG. NO. 1)
RECENT
LEGEND
SUPERJACENT ROCKS
LATE MESOZOIC (Great Valley Sequence)
MESOZOIC (Franciscan, Mariposa-Tuolumne)
MESOZOIC (?)- PALEOZOIC (?) (Sur Series, Calaveras)
OLDER GRANITE BASEMENT
REMOBILIZED BASEMENT (Batholith)
ULTRAMAFIC ROCKS
0 20 40 60 80 100
Km
0 25 50 75
MILES

FIGURE NO.5

Figure 5 Mesozoic geologic history of the Sierra Nevada and Coast Ranges.

a) Deposition of a thick sequence od type I graywackes and ophiolite in a Mesozoic eugeosyncline.

b) Emplacement of ultramafic intrusives. Partial metamorphism of eugeosynclinal rocks. Overthrusting westward of the partially metamorphosed rocks over a carbonate sequence (which now constitutes a part of the Sur Series).

c) Deposition of the meso-allochthonous sequences (Tithonian to early Late Cretaceous) on an allochthonous Franciscan basement in the area now submerged beneath sea-level (see fig. 6a).

d) Deposition of oldest neo-autochthonous sediments (Campanian) after a second episode of gravity sliding deformation involving meso-allochthonous sediments and their allochthonous basement (see fig. 6b).

e) Present structures, after repeated Cenozoic folding and faulting.

NOTES

Leave Morro Bay on State Highway 1. Turn right at northern edge of the town to State Highway 41. Proceed eastward for about six miles. Park near the western entry to the Los Padres National Forest.

Location 1. Melange unit 2 and ultramafic complex.

The blocks within the melange are mainly derived from the rodingite dikes of the complex. Other tectonic inclusions found are pyroxenite, ophicalcite, and type I graywackes, in a predominantly chloritic matrix. Walk east for about 1/4 mile along the highway to an exposure of peridotite, weathered brown and cut by rodingite dikes. Note the black serpentinite on the sides of the dikes. The igneous complex has been displaced en masse, without being pervasively sheared internally; the dike segments show only small displacements along shear fractures (photo 3).

Walk back to the car. Drive for about a mile eastward on State Highway 41 until it intersects the side road to Cerro Alto campground.

Location 2. Marmolejo Formation.

Note the even-bedded character of the interbedded siltstone, sandstone, and shale (photo 4). Stratal continuity is disrupted in shear zones. However, no lozenge-shaped boudines are present. Buchia piochii has been reported from this area (Bailey and others, 1964, pl. 2). The sandstone at this locality contains only traces of K-feldspar, although the upper Marmolejo sandstone farther north contains up to 10 percent K-feldspars.

Drive eastward on State Highway 41 for about 3 1/2 miles to a narrow road cut north of Frog Pond Mountains, where the highway intersects a private road. Park the car.

Location 3. Melange units 2 and 4.

Near the road intersection (on the side of the private road) is the contact between the Marmolejo Formation and a large diabase

block of melange unit 2. Additional tectonic inclusions of melange unit 2, such as serpentinite and Knoxville-like siltstone and shale, are exposed at the narrow road cut. Knoxville-like siltstone and conglomerate and serpentinite are found again on the roadside about one mile down State Highway 41. This section illustrates the fact (Hsu, 1968) that Knoxville-like rocks are mapped as the Marmolejo Formation where they occur within a mappable slab, but are mapped as undifferentiated Franciscan where they have been fragmented into unmappable tectonic inclusions and mixed with exotic blocks.

Farther east along State Highway 41 are exotic blocks of melange unit 4, which include chert, greenstone, type I graywackes, and glaucophane schist. Melange unit 4 is distinguished by its absence of Knoxville-like rocks from unit 2.

Proceed eastward on State Highway 41 for another 1/4 mile.

Location 4. Neo-autochthonous Asuncion Formation.

The basal conglomerate is exposed on the roadside. The clasts are mainly volcanic porphyry and plutonic rocks derived from the Coast Ranges batholith. No Franciscan debris has been positively identified. The conglomerate grades upward to graded arkosic sandstone beds exposed farther east down the road.

Return to Morro Bay on State Highway 41, observe the odometer at the intersection of State Highways 1 and 41 and use mileage references from this point. Proceed northward on State Highway 1 for 1.8 miles, turn left at the Yerba Buena Street exit, park the car and walk to the beach.

Location 5. "Broken formation B" (at the northern end of the Atascadero State Beach Park).

The "broken formation B" consists of interbedded type II graywackes and shale. The type II graywackes here contain 2 to 5 percent K-feldspars and older Franciscan debris such as red and green chert. The shale consists of chlorite, illite, and montmorillonite. Note the preservation of stratal continuity except for small displacements along extensional shears (normal faults). Such extensional strain represents the first stage in the formation of lozenge-shaped boudines.

Return to the car, proceed north on State Highway 1. Note, at mileage 7.8, that blocks of exotic chert rise above the meadow

of a marine terrace. At mileage 9.0, turn left to a driveway near a large chert block, park, walk across a meadow to the beach.

Location 6. Melange unit 3.

A small slab of vertically-dipping red chert and greenstone (upper ophiolites) is exposed on the shore.

Descend to the beach. Note the chaotically deformed nature of the melange. Blocks of chert and graywacke are very common. The latter are typically type II graywackes, similar to those of the "broken formation B" at Location 5.

Walk westward along the beach for about half a mile to Location 7, at a small coastal prominence.

Location 7. Melange unit 1.

Type III graywacke blocks, detached from the "broken formation A", are present here as melange inclusions. Other tectonic inclusions are type II graywackes, chert, greenstone, and blue schist.

Walk westward about half a mile farther. The type III graywacke beds show less stratal disruption and exotic blocks become very rare. The last outcrops along the beach east of the mouth of Villa Creek represent a transition to the overlying "broken formation A", which is exposed on the west side of the creek.

Walk back to the car. Proceed northward on State Highway 1 to mileage 21.3 and turn left on Moonstone Beach Drive. Drive north for 1/4 mile and park. Walk down to the beach.

Location 8. "Broken formation A".

Note the well-bedded character of the formation A. Disruption of stratal continuity can be observed but is relatively minor. The shale beds are fractured in part and show less ductility in deformation than the pelitic matrix of the melanges. Walk north along the beach to the mouth of Leffingwell Creek. Note graded beds, disrupted by predominantly extensional shears. Note also that the type III graywackes locally contain abundant debris derived from older Franciscan rocks, such as green and red chert chips. The graywacke contains 10 to 20 percent K-feldspar. A shale interbed here yielded Upper Cretaceous fossil pollens and spores.

Walk back to the car, return to State Highway 1. Proceed north to mileage 29.4 (1 1/4 mile before the side road to Hearst Castle). Park and walk down to the beach.

Location 9. Melange units 3 and 2.

Walk southward from the mouth of Broken Bridge Creek. After passing through an outcrop of exotic serpentinite, you are in melange unit 3. Proceed southward along the beach for about 1 mile to observe the chaotic structures of this melange (photos 5, 6, 7).

Walk back to the mouth of the Broken Bridge Creek and then farther north for about 1/4 mile to examine melange unit 2, which includes several serpentinite blocks. A block of conglomerate is present in the melange; the conglomerate contains a variety of Franciscan debris as clasts.

North of San Simeon Point, you may find along the coast serpentinite and red serpentinite breccia as tectonic inclusions. Melange unit 2 is characterized by the presence of such blocks detached from the overlying slabs of ultramafic complex and Knoxville-like rocks.

Return to the car, drive north along State Highway 1 about 6 1/2 miles. Turn left on side road to Piedras Blancas Lighthouse. Leave the car at the parking lot opposite Seal Rock.

Location 10. Upper ophiolites and melange unit 2.

The cherts and ophiolites at the Piedras Blancas Point constitute a slab-sized inclusion in melange unit 3.

Walk southeastward along the rocky beach, observe the interbedded green chert, basaltic tuff and cherty shale. The upper part of the unit (at southeast side of the point) consists of chert only, which has been recrystallized to quartzite. The thick bedded quartzite grades downward to interbedded chert and green cherty shale, which have been folded into minor chevron folds (presumably during pre-Tithonian deformation). Near the parking lot are largely weathered interbedded palagonite tuff and tuff breccia.

Return to the lighthouse parking lot. Walk northward down to the beach again. Note a transition from interbedded chert and greenstone to greenstone (tuff), to greenstone with scattered pillows. The

last few outcrops south of a wide sandy beach are mainly pillow lava; the shape of pillows shows that the beds face southward and that we have been walking down the section.

Location 11. Sheared graywacke.

Cross the sandy beach to observe the intensely sheared graywacke and shale. The graywacke beds are lithologically similar to those of the type II graywacke near Morro Bay, but here the graywacke beds are broken into many fragments and lozenge-shaped boudines. Note the brittle fracturing of the graywacke and ductile flow of the shaly matrix. Note also the rotation of laminated siltstone fragments of lozenge-shape boudines (photo 8). This is one of the best sites to observe the combined extensional and compressional strains of the Franciscan rocks.

Walk back to the car. Drive northward from the lighthouse to Breaker Point. Park about 1/4 mile south of Breaker Point on side of State Highway 1. Walk across a meadow to the beach.

Location 12. Serpentinite breccia.

Note the large red serpentinite and green gray diabase clasts of the conglomerate and breccias. Walk northward along the shore at low tide. Observe the contact between the breccia and the serpentinite of the underlying ultramafic complex. Traces of weathered red serpentinite are present near the top of the basement complex. The contact is depositional, although modified slightly by Cenozoic faulting. This serpentinite breccia was previously mapped as a Tertiary pyroclastic (Taliaferro in Jennings, 1959).

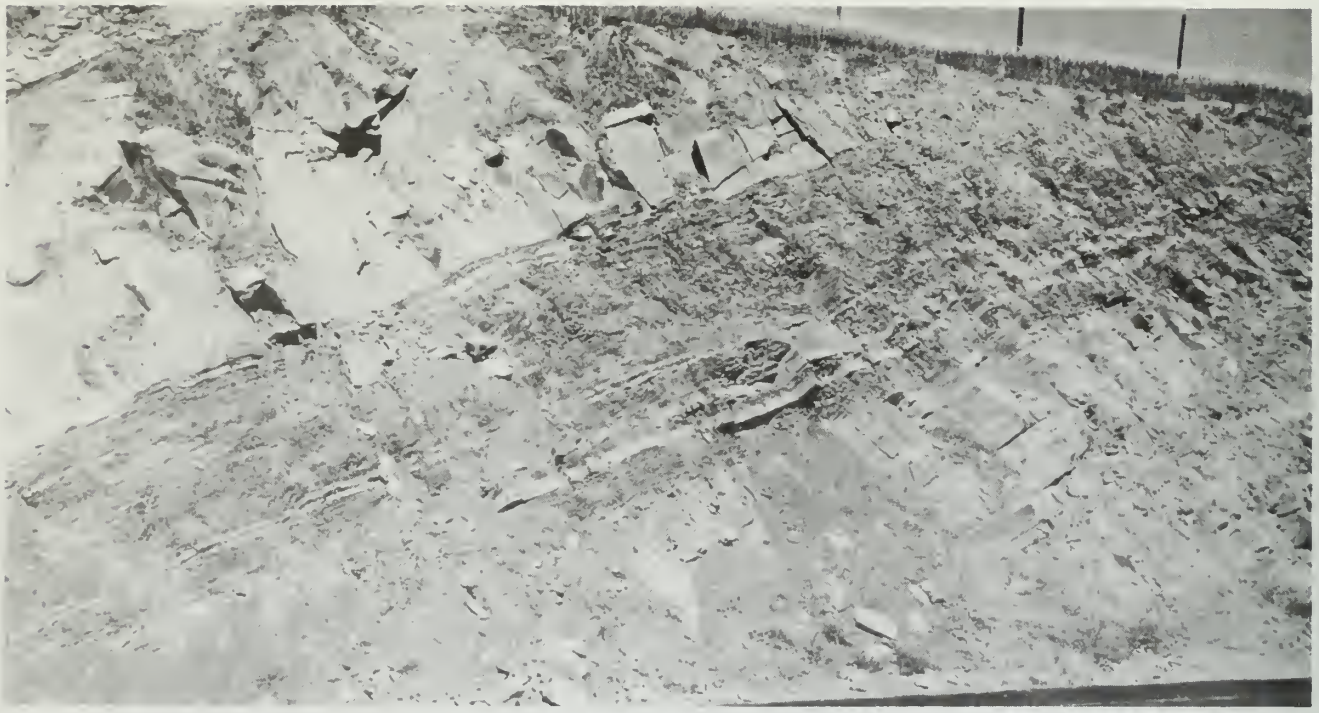


Photo 1. Well-preserved original stratal continuity. "Broken formation A" on State Highway 1, eight miles south of Cambria.

Photo 2. Disrupted original stratal continuity. "Broken formation A" on the seashore one mile south of the village of Cambria Pines. Note the lozenge-shaped boudines.

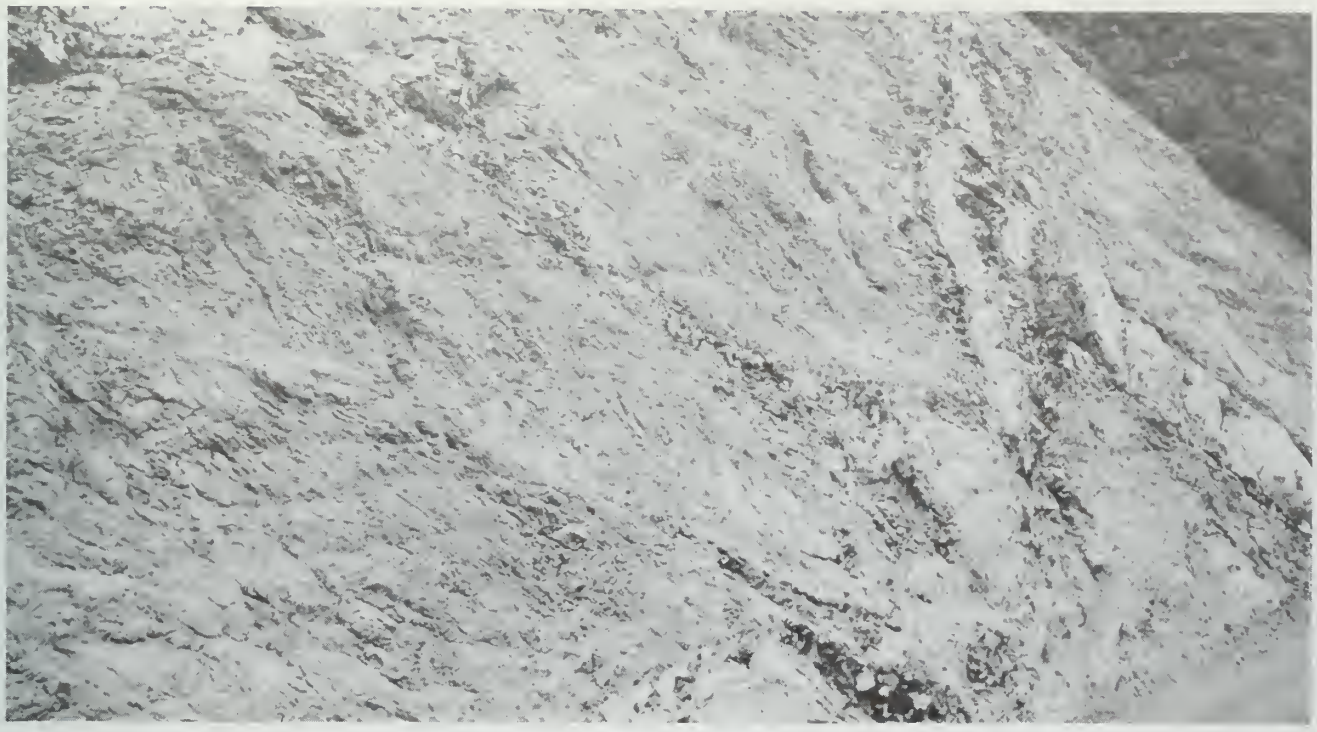


Photo 3. Ultramafic complex, Black Mountain slab. On State Highway 41 east of Morro Bay (Field trip location 1). Note the small displacement of dike segments.

Photo 4. Well-preserved original stratal continuity. Marmolejo Formation on State Highway 41 (Field trip location 2).

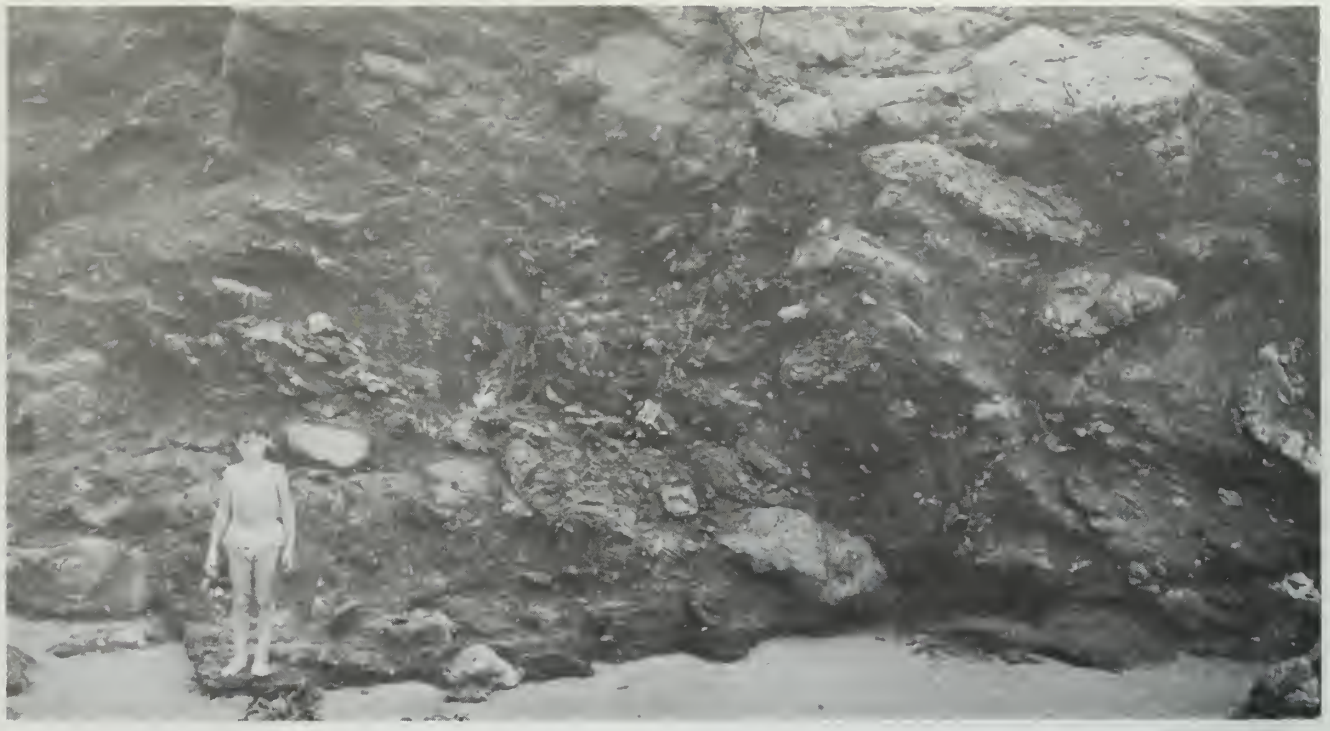


Photo 5. Melange unit 3 at the coast three miles southeast of San Simeon village. Note the fragments and small blocks of greenstone, graywacke, chert, and blue schist in a ductily deformed matrix.

Photo 6. Melange unit 3 at the coast three miles southeast of San Simeon village. Note the large block of graywacke to the right of the child.

Photo 7. Melange unit 3 at the coast three miles southeast of San Simeon village. Note the two large blocks of chert.

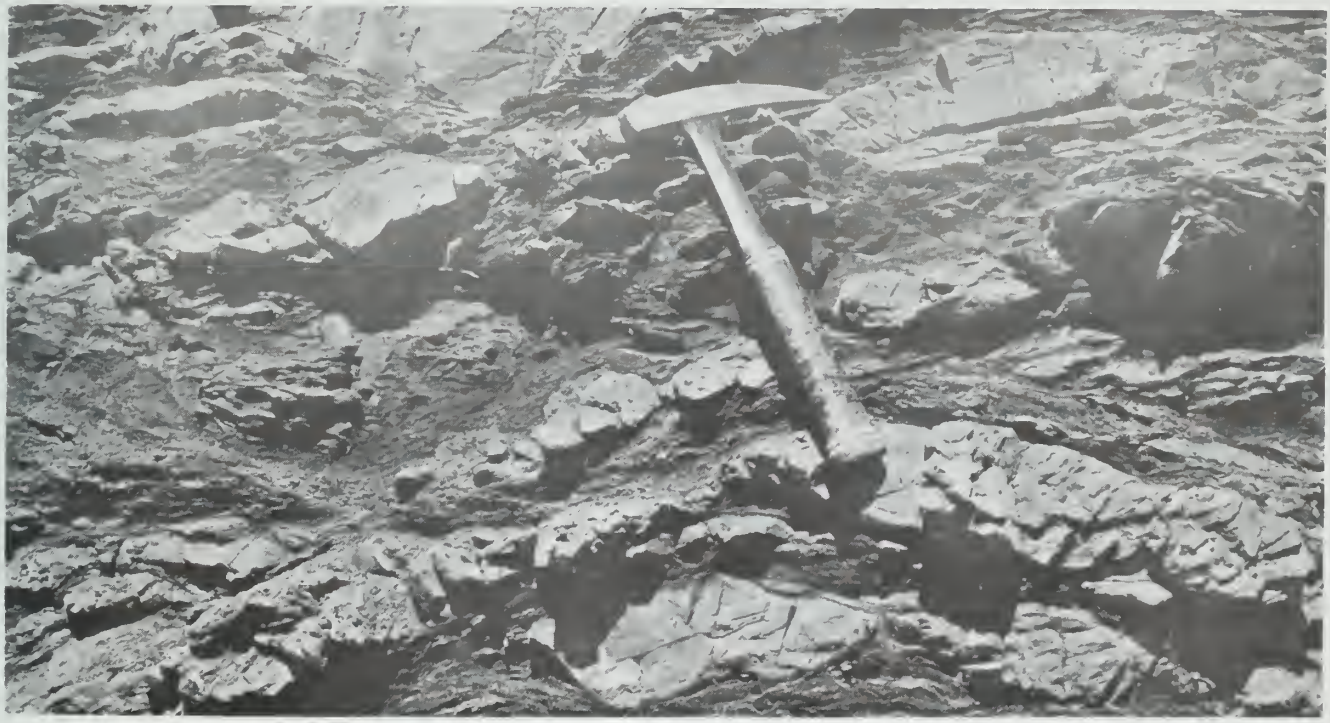


Photo 8. Completely disrupted original stratel continuity. Type II graywackes in melange unit 3 at the coast north of Piedras Blancas Point (Field trip location 11).

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